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Method for Developing Ozone Exposures That Mimic Ambient Conditions in Agricultural Areas

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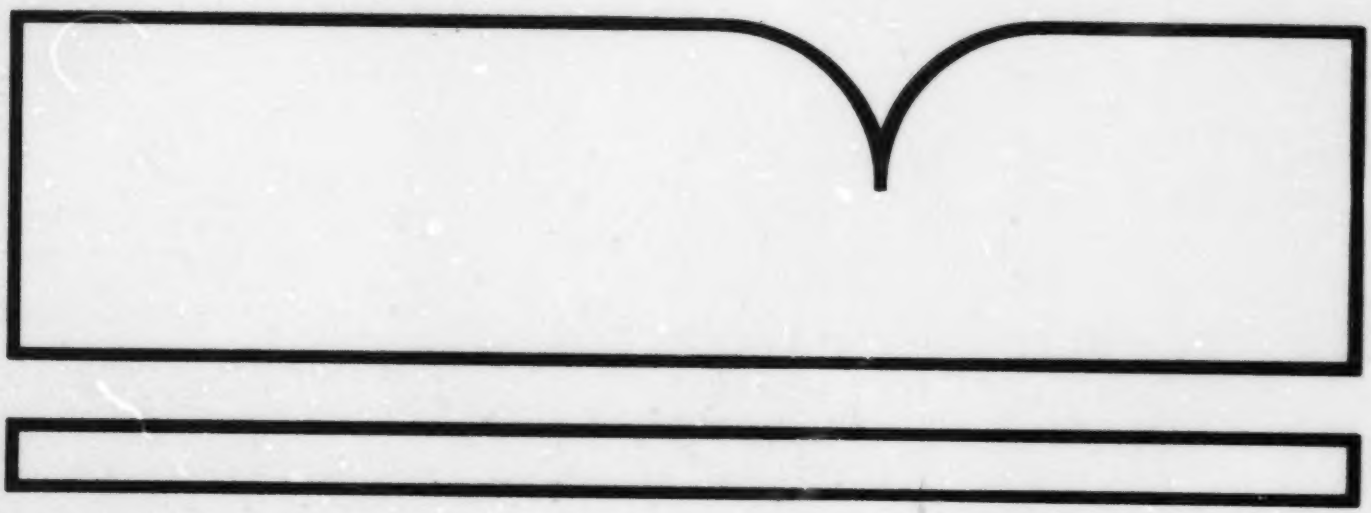

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A METHOD FOR DEVELOPING OZONE EXPOSURES THAT MIMIC AMBIENT CONDITIONS IN AGRICULTURAL AREAS

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Abstract—Ozone fumigations that mimic ambient ozone distributions facilitate the development of links between (1) vegetative effects results that are generated in the laboratory and the field and (2) predictive effects models that depend upon ambient air quality data. Experimental exposure profiles were constructed from a readily available ambient air quality data base (i.e. EPA SAROAD). Air quality data from selected monitoring sites were characterized over the 5-month growing season by identifying (a) the number of occurrences of hourly ozone concentrations equal to or above 0.07 ppm, (b) the number of days of each episode, (c) the number of days between episodes and (d) the rate of rise and decline of the daily ozone concentrations. An episodic profile was constructed incorporating the information into a representative 30-day ozone exposure pattern in which the concentration was changed on an hourly basis. In order to compare treatments having equivalent exposures (sum of hourly ozone concentrations equal to or above a minimum value) but dissimilar temporal distributions of hourly concentrations, a second profile was created. This profile was characterized by a repeated daily incremental rise and decline in ozone concentration that had the same hourly maximum concentration each day. The use of experimental exposure profiles mimicking ambient air quality characteristics and applied under controlled experimental conditions permits the examination of important exposure parameters on plant response.

Key word index: Air quality, ambient, distribution patterns, episodes, exposure regimes, integrated exposure index, 7-h seasonal averages, ozone, peak concentrations, simulated exposure profiles.

1. INTRODUCTION

To identify and predict the possible effects of ambient ozone exposures on crops, it is necessary to develop experimental exposure regimes that represent ambient conditions. Previous studies have used exposures that did not reflect the episodic nature of ozone exposures to measure the response of vegetation to ozone. For example, Heagle *et al.* (1973) applied 6-h constant ozone exposures to determine the impact of ozone on the yield of corn and Neely *et al.* (1977) used constant 7-h exposures to determine the effect of ozone on alfalfa. However, with the advent of computer technology (Harper *et al.*, 1986), it is now possible to precisely control ozone concentrations on an hourly basis in exposure facilities.

The use of experimental exposure profiles mimicking ambient air quality and applied under experimentally controlled conditions allows studies to examine which components of exposure (concentration, frequency of occurrence, duration, and time between events) most affect vegetation injury or yield. Previous studies have indicated that the peak ozone concentration is an important exposure parameter influencing plant response to ozone. Musselman *et al.* (1983) investigated the effects of different ozone exposure regimes on bean plants (*Phaseolus vulgaris* L. cv. Red Kidney). They showed that higher concentrations over shorter periods of time elicited a greater growth reduction and injury response than the constant exposure regime, although both fumigations had identical exposure values (ppm × h). Ashmore (1984) showed that the adverse effects of ozone episodes on radish (*Raphanus sativus*) can be associated with the percent of days the hourly averaged ozone concentrations exceeded 0.06 ppm. In addition to the importance of peak ozone concentration, the actual sequence of hourly ozone concentrations may also be significant (Runeckles and Rosen, 1977; Johnston and Heagle, 1982). The construction of realistic ozone fumigation profiles will permit studies comparing the different exposure components by varying hourly averaged concentrations over time while retaining similar exposure characteristics (e.g. 7-h seasonal mean, integrated exposure and frequency of occurrence).

This paper outlines an approach for developing experimental exposure profiles that simulate ambient ozone exposure conditions from available air quality data. While ambient profiles for a specific site may vary from year-to-year and the timing of the episodes in

relation to stage development and climate sensitivity may be important, the creation of simulated ambient exposures represents an opportunity to identify and weight those exposure dynamics that are most important in affecting vegetation.

2. EXPERIMENTAL APPROACH

Using annual summary percentile information published by EPA (1979), all ozone monitoring sites in the United States which (1) were sampled during the year 1978; (2) recorded at least 4380 hourly measurements during the year; and (3) experienced a maximum concentration equal to or greater than 0.10 ppm, were identified. The hourly ozone concentration is that value that represents an average of all concentrations measured over an hourly time period. While ozone concentration distributions may vary from site-to-site, the appearance of high concentrations over a short time period is a regional observation that is associated with meteorological variables (Wolff *et al.*, 1977; EPA, 1978; Spicer *et al.*, 1979). Therefore, sites designated as rural and non-rural were included in the analysis.

With the assistance of data published in the 1978 Census of Agriculture (Department of Commerce, 1981), those sites located in major agronomic crop production areas were identified for further analysis. The selected sites were ranked by calculating, on an annual basis, the integrated exposure index, using 0.10 ppm as per the method developed by Lefohn and Benedict (1982). The annual percentile summary information published by the United States Environmental Protection Agency (EPA, 1979) provided raw data. The integrated exposure index was calculated by summing the hourly concentrations over all concentrations equal to or greater than 0.10 ppm. The index provides an indication of the number of occurrences and magnitude of the concentrations above a minimum level. The integrated exposure values ranged from approximately 0 to over 200 ppm h. To identify only those sites with frequent occurrences of ozone greater than 0.10 ppm, a decision was made to eliminate from further consideration all monitoring sites with integrated exposure indices less than approximately 5 ppm h.

The monitoring sites at Conneaut and Middletown, Ohio were selected for developing detailed exposure patterns. The selection was based on the above criteria and the assumption that by selecting sites where the annual integrated exposure index was approximately 30 ppm-h (based upon a 0.10 ppm minimum concentration), a sufficient number of hourly ozone concentrations at elevated levels would be present to elicit a vegetation response.

The detailed characterization of the two Ohio monitoring sites used a minimum concentration of 0.07 ppm to take into consideration the possibility that the occurrence of hourly concentrations above this value might elicit an effect on vegetation. Hourly ozone monitoring data by hour, day and month were obtained from the SAROAD data base for April through to October 1978 for both sites. The air quality information for these monitoring sites was characterized by identifying the (a) number of occurrences of hourly averaged values equal to or above 0.07 ppm, (b) number of days of each episode (the onset of an episode-day is defined as an hourly ozone concentration equal to or above 0.07 ppm and the termination of an episode is a day when an hourly average concentration equal to or above 0.07 ppm was not observed) and (c) number of days between the end of one episode and the beginning of the next.

Following the data analyses, an episodic profile that reflected the number of occurrences, duration, and time between episodes of ambient ozone was constructed. There were a number of days during a month when hourly averaged concentrations were not equal to or above 0.07 ppm; these 24-h periods were considered 'resting' days. For these resting days, a representative pattern of 24 hourly concentrations, based upon the two Ohio sites, was used.

A second profile was created that had a daily incremental rise and decline in ozone concentration, the same hourly time series each day, and the same hourly maximum concentration each day. The two profiles (episodic and daily) were designed to have equivalent integrated exposures (ozone concentration summed over time) over a 30-day period and dissimilar daily distributions of hourly concentrations.

3. RESULTS

Summaries of the 7-month ozone percentile distribution data, as well as 7-h daylight (0900–1559) seasonal averages, and integrated exposure index values for the 7-month period, are shown in Tables 1 and 2 for the corn and hay producing areas. The highest integrated exposure index value (74.96 ppm h) found in the 1978 SAROAD data base for a site in a large corn-producing county was Middletown, Ohio (Table 1). The site was designated in the SAROAD data base as suburban-commercial. The hourly averaged ozone data from the SAROAD data base were reviewed for the Middletown site from April through to October 1978. During this period, the site experienced 811 hourly averaged ozone concentrations equal to or greater than 0.07 ppm, 123 days of episodes (concentrations equal to or greater than 0.07 ppm), and an average of approximately 3 days between episodes.

Table 1. Monitoring sites where corn production is high and elevated ozone is present during the 7-month growing season (concentration in ppm)

Site	County and State	Percentiles 10	30	50	70	90	95	99	Max.	7-h exp. average	Integrated exposure (ppm h)
Madison Co.	Madison, IL	0.010	0.014	0.027	0.042	0.070	0.084	0.113	0.188	0.052	41.99
Wood River	Madison, IL	0.000	0.001	0.021	0.035	0.067	0.080	0.122	0.197	0.049	41.40
Waukegan	Lake, IL	0.000	0.007	0.017	0.029	0.050	0.070	0.110	0.240	0.035	23.82
Skokie	Cook, IL	0.000	0.008	0.020	0.032	0.054	0.072	0.114	0.263	0.037	23.51
Middletown	Butler, OH	0.000	0.012	0.028	0.049	0.081	0.096	0.131	0.204	0.058	74.96
Clark Co.	Clark, OH	0.000	0.015	0.032	0.048	0.080	0.095	0.120	0.188	0.054	68.03
Preble Co.	Preble, OH	0.005	0.020	0.035	0.050	0.070	0.082	0.105	0.162	0.046	44.26
Sheboygan Co.	Sheboygan, WI	0.008	0.020	0.031	0.043	0.065	0.086	0.127	0.256	0.043	39.82
Racine	Racine, WI	0.005	0.016	0.025	0.034	0.058	0.074	0.116	0.250	0.036	28.03

Table 2. Monitoring sites where hay production is high and elevated ozone is present during the 7-month growing season (concentrations in ppm)

Site	County and State	Percentiles 10	30	50	70	90	95	99	Max.	7-h exp. average	Integrated exposure (ppm h)
Riverside	Riverside, CA	0.000	0.010	0.020	0.050	0.120	0.150	0.200	0.370	0.089	145.06
Bakersfield	Kern, CA	0.000	0.010	0.020	0.050	0.080	0.100	0.120	0.150	0.069	92.01
Fresno	Fresno, CA	0.000	0.010	0.020	0.040	0.070	0.080	0.110	0.150	0.052	40.80
Conneaut	Ashtabula, OH	0.007	0.028	0.040	0.053	0.080	0.100	0.141	0.199	0.058	71.44
Sheboygan Co.	Sheboygan, WI	0.008	0.020	0.031	0.043	0.065	0.086	0.127	0.226	0.043	39.82
Columbia	Columbia, WI	0.015	0.030	0.041	0.052	0.070	0.080	0.101	0.234	0.055	39.23

Hay, another crop of major importance, is grown in many parts of the United States. The range of integrated exposure index values was from 145.06 ppm h (Riverside, California) to 10.90 ppm h (Glen Falls, New York) (Table 2). Because the ozone exposures in southern California are usually higher than those in other parts of the United States, monitoring sites from this part of the country were not included in the analysis. Monitoring data from the Conneaut, Ohio site were selected for further analysis because its exposure index value (71.44 ppm h) potentially represented an exposure regime that might result in damage to hay. The site was designated in the SAROAD data base as suburban-residential. Over the 7-month period, the site experienced 749 hourly averaged ozone concentrations equal to or greater than 0.07 ppm, 101 days of episodes, and an average of approximately 3.5 days between episodes.

Data from the two Ohio sites (Middletown and Conneaut) were used to develop a base episodic profile. This profile was based upon a 30-day month and a 24-h daily ozone exposure pattern. The number of hourly occurrences equal to and above the minimum concentration (0.07 ppm), the number of days that each episode lasted, the number of days between episodes, and the extent of the rise and decline of daily ozone hourly concentrations were characterized. The majority of the elevated ozone levels occurred in May through to September; this period was used to characterize the episodic nature of the ozone exposure.

There were 19 days when an hourly averaged concentration equal to or greater than 0.07 ppm occurred. The number of hourly occurrences equal to or greater than 0.07 ppm was 196 in a 30-day period. The number of days between episodic occurrences averaged 4 during the 30-day period and the number of consecutive days that the ozone concentration equalled or exceeded 0.07 ppm, for at least 1-h, ranged from 3 to 7 days. In order to create the base episodic profile (Fig. 1a),individual hourly ozone concentrations were placed in each hour of the day for a 30-day period to meet the above set of exposure characteristics.

A comparison of the percentile distributions for the two Ohio sites and the base episodic profile is provided (Table 3). Based on a minimum concentration of 0.07 ppm, the integrated exposure value for the distribution was calculated to be approximately 19.45 ppm h per month. For comparative purposes, this value would be 136.15 ppm h if the distribution pattern was repeated each month over a 7-month period. This value is higher than the 71.44 and 74.96 ppm h integrated exposure values calculated over a 7-month period for Conneaut and Middletown, respectively. Our experimental base profile contained a larger number of hours, in the range 0.07–0.09 ppm, when compared to the two Ohio sites. The major concern, however, was in reconstructing the episodic nature or frequency of exposure, and not in reproducing exactly the concentration distribution. The distribution of the simulated hourly concentrations appeared to resemble typical monthly ambient ozone exposures for sites experiencing elevated ozone concentrations (Fig. 2).

The daily exposure profile was also created from monitoring data for the two Ohio sites. The exposure profile was designed to be low at midnight (0.017 ppm) and gradually rise to a maximum hourly averaged ozone concentration of 0.105 ppm by 2 p.m. Following the appearance of the peak concentration, there was a gradual reduction until 10 p.m. (0.017 ppm) (Fig. 1b). While the base daily exposure profile was not designed to mimic ambient air quality, it was designed to have a

Table 3. Comparison of air quality characterization parameters (concentrations in ppm) for a 7-month period

Site	Percentiles 10	30	50	70	90	95	99	Max.	7-h avg.	Integrated exposure
Conneaut	0.007	0.028	0.040	0.053	0.080	0.100	0.141	0.199	0.058	71.44
Middletown	0.000	0.012	0.028	0.049	0.081	0.096	0.131	0.204	0.058	74.96
*Episodic base profile	0.018	0.025	0.040	0.063	0.099	0.119	0.153	0.170	0.074	136.15

*The percentile information for the episodic base profile was constructed from the 30-day synthesized exposure regime.

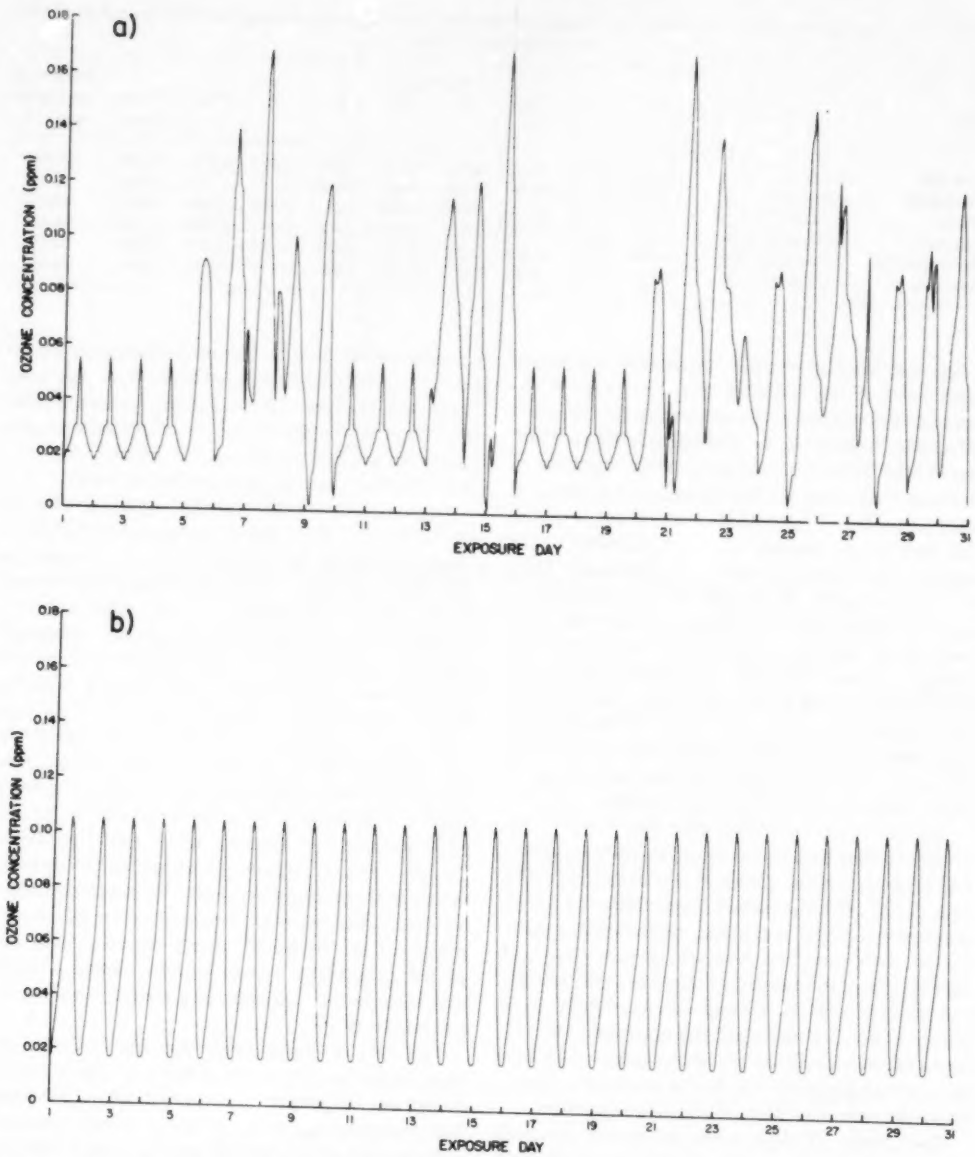

Fig. 1. 30-day episodic exposure profile (a) and daily exposure profile (b) constructed from the SAROAD data of Conneaut and Middletown, Ohio. The two profiles have equivalent integrated exposure values. Tic mark on X—axis is at midnight for each day.

30-day integrated exposure value approximately equal to the episodic profile (19.45 ppm h). The resultant integrated exposure value was 18.90 ppm h.

Distinct treatment levels can be created from the episodic or daily exposure profiles for use in chronic exposure growth studies. The hourly ozone values equal to or greater than 0.07 ppm over the 30-day period may be multiplied by a constant factor to either raise or lower the hourly concentrations (thus maintaining equivalent 30-day integrated exposure values).

4. DISCUSSION

When attempting to correlate laboratory and field experimental results with actual conditions, it is important to understand those exposure characteristics that play key roles in eliciting vegetation growth reductions. The work by Lefohn and Tingey (1984) underscores the importance of adequately characterizing ambient exposures prior to designing experimental fumigation experiments. Oshima *et al.* (1977) have

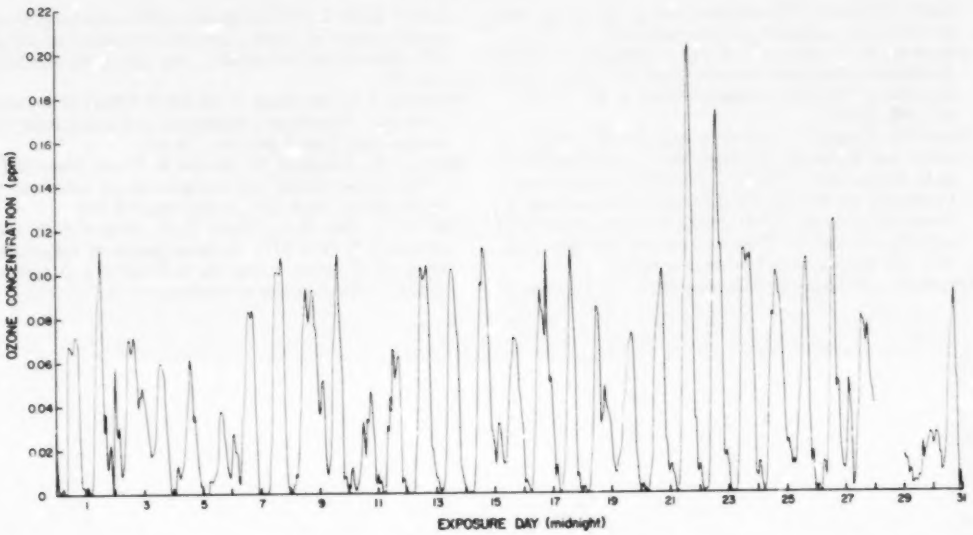

Fig. 2. Hourly ozone concentration for the month of August 1978 from Middletown, Ohio for SAROAD Site No. 364340004H01.

noted that exposure profiles should reflect the temporal element or number of events over a growing season. This temporal element was incorporated in developing our experimental exposure profiles.

The application of the simulated ambient exposures to field and laboratory studies provides an extra dimension for properly assessing the potential effects of air pollutants on vegetation and identifying those parameters that best describe pollutant exposure. For example, Hogsett *et al.* (1985) used the two exposure profiles to compare a set of episodic exposure regimes with daily exposures. The authors reported that an ozone episodic exposure pattern, applied to alfalfa over a 133-day growth period, elicited a greater response than a daily peak exposure pattern. The two profiles had similar integrated exposure values and different 7-h seasonal means. The authors noted that the 7-h (0900–1559) means for the two profiles were inversely correlated with the observed growth response. The episodic profile had a smaller seasonal mean, yet caused a greater yield reduction.

If the occurrence and distribution of episodic exposures are important in eliciting a growth response, then it is necessary to identify and use those mathematical parameters that characterize the episodic occurrences. Further attention should be given to identifying parameters that adequately describe the appearance of episodic exposures.

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REFERENCES

Ashmore M. R. (1984) Effects of ozone on vegetation in the United Kingdom. *Proc. Workshop on the Evaluation and Assessment of the Nature, Magnitude and Geographical Extent of Effects of Photochemical Oxidants on Human Health, Agricultural Crops, Forestry, Materials and Visibility*, hosted by the Swedish Environmental Research Institute, Goteborg, Sweden, 29 Feb.–2 Mar. 1982. ISBN 91-7810-1530.

Department of Commerce (1981) 1978 Census of Agriculture Summary and State Data, United States. AC78-A-51. Washington, DC.

Environmental Protection Agency (1979) Air Quality Data 1978 Annual Statistics Including Summaries with Reference to Standards. EPA-450/4-79-037. Washington, DC.

Environmental Protection Agency (1978) Air Quality Criteria for Ozone and Other Photochemical Oxidants. EPA-600/8-78-004. Washington, DC.

Harper S. L., Tingey D. T. and Hogsett W. E. (1986) Automation of experiments with a handheld programmable calculator. *Am. Lab.* **17** (in press).

Heagle A. S., Body D. E. and Heck W. W. (1973) An open-top field chamber to assess the impact of air pollution on plants. *J. Envir. Qual.* **32,** 353–361.

Hogsett W. E., Tingey D. T. and Holman S. R. (1985) A programmable exposure control system for determination of the effects of exposure regimes on plant growth. *Atmospheric Environment* **19,** 1135–1145.

Johnston J. W. and Heagle A. S. (1982) Response of chronically ozonated soybean plants to an acute ozone exposure. *Phytopath.* **73,** 387–389.

Lefohn A. S. and Benedict H. M. (1982) Development of a mathematical index that describes ozone concentration, frequency, and duration. *Atmospheric Environment* **16,** 2529–2532.

Lefohn A. S. and Tingey D. S. (1984) The co-occurrence of

potentially phytotoxic concentrations of various gaseous air pollutants. *Atmospheric Environment* **18**, 2521–2526.

Musselman R. C., Oshima R. J. and Gallavan R. R. (1983) Significance of pollutant concentration distribution in the response of 'red kidney' beans to ozone. *J. Am. Soc. Hort. Sci.* **108**, 347–351.

Neely G. E., Tingey D. T. and Wilhour R. G. (1977) Effects of ozone and sulfur dioxide singly and in combination on yield, quality and N-fixation of alfalfa. In *International Conference on Photochemical Oxidant Pollution and its Control. Proceedings*, Vol. II, (edited by Dimitriodes B.), pp. 663–673. EPA-600/3-77-001b. Research Triangle Park, NC. U.S. Environmental Protection Agency.

Oshima R. J., Bragelmann P. K., Baldwin D. W., Van Way V. and Taylor O. C. (1977) Responses of five cultivars of fresh market tomato to ozone: a contrast of cultivar screening with foliar injury and yield. *J. Am. Soc. Hort. Sci.* **102**, 286–289.

Runeckles V. C. and Rosen P. M. (1977) Effects of ambient ozone pretreatment on transpiration and susceptibility to ozone injury. *Can. J. Bot.* **55**, 193–197.

Spicer C. W., Joseph D. W., Sticksel P. R. and Ward G. F. (1979) Ozone sources and transport in the northeastern United States. *Envir. Sci. Technol.* **12**, 975–985.

Wolff G. T., Lioy P. L., Wight G. D., Meyers R. E. and Cederwall R. T. (1977) An investigation of long-range transport of ozone across the midwestern and eastern United States. *Atmospheric Environment* **11**, 797–802.

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